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Quantitative decision parameters of rural electrification planning: A review based on a pilot project in rural Nepal

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ABSTRACT

Many countries including Nepal utilize qualitative parameters and/or judgment in order to appraise stand-alone off-grid project sites. This paper reviews on-going efforts for electrification in rural Nepal, and quantitative parameters available to support this planning process of remote mountainous (rural) villages utilizing the off-grid renewable system or the national power grid. These parameters are computed and analyzed with reference to the data available for Asian Development Bank supported wind/solar hybrid pilot project in Nawalparasi district in western Nepal. Finally this paper presents some recommendations on utilizing those quantitative parameters including zoning to insulate feasible off-grid sites from unplanned on-grid expansion. With such planning and policy in place the interest of private sector for remote rural electrification is bound to grow, perhaps much faster than current rate, to complement efforts of the local government and development partners.

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1. Introduction

Energy poverty has been persisting in rural Nepal, leading to prolonged economic poverty. The electrification rate in Nepal remains as one of the lowest among the developing countries. According to the data from the International Energy Agency (Fig. 1), the electrification rate for Nepal stood at 44% in 2009,

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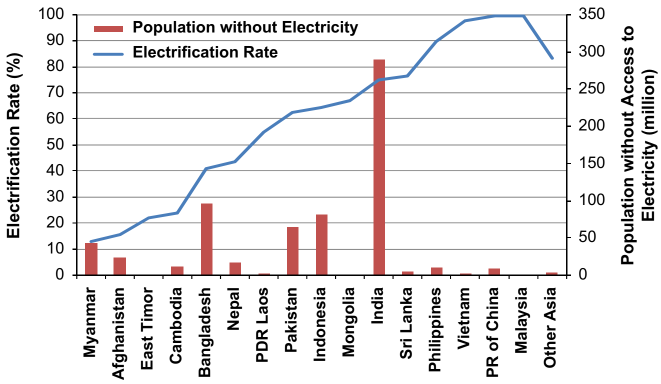

Fig. 1. Access to electricity in 2009 [1].

which is higher than that in Myanmar (13%) and Bangladesh (41%), but it lags far behind that of Pakistan (62%) and India (75%). It is estimated that only about 20% of rural areas of Nepal have reliable access to electricity. There are still 16.5 million rural Nepalese, about 62% of the country's total population of 26.6 million, that have never used electricity in their homes. The country's total electricity generation capacity is stagnated at 689.3 MW, which is less than that of a single modern power generation unit in some developed countries. Without electricity, industrial and commercial businesses can hardly be developed, and basic social services (such as health care and education) can barely be provided.

Although tangible progresses for rural electrification in Nepal have been made in past decades, further expansion of the national power grid into vast rural areas is anticipated to be costly and slow. Serious challenges exist because of the lack of physical infrastructure (such as roads), technical capacities and financial resources, as well as because of the inherent difficulties in construction and maintenance of power grid facilities across complex geographical terrains and survival through harsh weather conditions. Nepal's total territory of 147,181 square kilometers stretches from east to west, across three ecological zones (the Southern Range, the Mid Range and the Northern Range) with a mean length of 885 km and widens from north to south with a mean breadth of 193 km. The altitude ranges from 70 m (m) to 8848 m and the climate varies from tundra to polar. According to the data from the 2011 census conducted by the Government of Nepal (GON), as presented in Table 1, nearly half of the country's total population lives in hilly and mountainous areas, which cover 77% of the country's territory. Both the population density and the average income are lower in these areas than that in the Terai, Southern Range of flat land, resulting in relatively smaller demand for electricity in widely distributed villages. Extending the national power grid over long distances to serve such remote villages with potentially low volumes of electricity consumption could be highly burdensome in both financial and operational terms.

Nevertheless, Nepal is endowed with abundant renewable energy resources. In most remote villages, there are sufficient hydro, wind, solar, biogas, and biomass resources that can be exploited at little resource costs to generate carbon-free electricity without any reliance on fossil fuels. If not effectively utilized, these non-storable indigenous renewable resources would be wasted. Major energy resources in Nepal consist of fuel woods, agricultural residues and animal wastes. The theoretical potential of known indigenous energy sources, excluding solar energy, amounts to 1970 million GJ annually thus indicating that Nepal has the potential to meet and exceed all its energy needs [4].

Nepal has recently implemented a nodal program “National Rural and Renewable Energy Program (NRREP)” funded by Government of Nepal and different development partners. The objective of the program is to improve the living standard of rural women and men, increase employment of women and men as well as productivity, reduce dependency on traditional energy sources and attain sustainable development through integration of alternative energy sources with the socio-economic activities of women and men in rural communities. The NRREP is designed in a single modality approach with three main components [5]: (a) Central Renewable Energy Fund (CREF), (b) Technical Support and (c) Business Development for Renewable Energy and Productive Energy Use. The program will be continued for 5 years until July 15, 2017. Table 2 presents the average annual targets and estimated financing for the NRREP.

Access to the road in rural area can also influence the decision on selecting an approach toward rural electrification. Rural road density in each district and development region of Nepal is published in [7]. Nepal has very low density of road with about 17 km per 100 km^2 of land area. The total length of motorable road has reached to 25,115 km at the end of fiscal year 20011/12, of which blacktopped, graveled and earthen roads constitute 7474 km, 6077 km and 11,565 km respectively [8]. Table 3 presents average value of road density in the three ecological belts of Nepal.

2. Rural electrification approaches in Nepal

Apparently, the demand for electricity in a remote village can be satisfied by either extending the coverage of the national power grid (the on-grid approach) or constructing and operating a stand-alone system based on renewable energy resources (the off-grid approach) all at the local level. Many factors can affect the critical decision on selecting between the off- and on-grid approaches, including:

- the geological location of the village and the total length for a suitable route to connect the village to the national power grid;
- the load volumes for electricity demand in the village in the mid- and long-run;
- the availability and reliability of renewable energy resources that can be effectively harvested using proven technologies;
- the capacity of electricity generation and transmission covered under the national power grid;
- the public policies and incentives for promoting rural electrification and renewable energy development; and
- the institutional capacities and all-in life-cycle costs for adopting different approaches.

Rural electrification in Nepal is moving forward mainly through four institutions: (a) Nepal Electricity Authority (NEA), (b) Grant Projects (ADB, World Bank and others) (c) Alternative Energy Promotion Center (AEPC), and (d) Community Electricity Users Cooperatives. The main actor of the on-grid approach is NEA and that of the off-grid approach is the AEPC.

2.1. The off-grid approach

The off-grid approach emphasizes maximizing and optimizing uses of local renewable resources to meet local energy needs. Electricity production, distribution and consumption can co-exist within the same village. In fact, Nepal is famous for utilizing traditional water-wheels (*ghattas*) ever since early 20th century. These primitive water-wheels are still being improved as multi-purpose power units for agro-processing and electricity generation. As early as in 1970, the GON initiated a promotion program that could subsidize, through the Agricultural Development Bank of Nepal, up to 75% of the total costs on electro-mechanical equipment for micro-hydropower plants in order to electrify remote rural areas of the country.

The Alternative Energy Promotion Center (AEPC) under then Ministry of Science and Technology was established by GON on

Table 1
Population distribution among the three geographic regions of Nepal [2,3].

Geographic region	Terrain types	Area		Population		Population density	Average per capita income [3] (NRs)	Number of households	Average family size
		km^2	(%)	Total	(%)	(per km^2)			
Northern range	Mountain	51,955	35.3	1,795,354	6.7	34.6	34,633	379,098	4.74
Mid-range	Hills	61,374	41.7	11,475,001	43.1	187.0	46,224	2,644,024	4.34
Southern range	Terai	33,999	23.1	13,350,454	50.2	392.7	38,549	2,636,862	5.06
Nepal		147,181	100.0	26,620,809	100.0	180.9	41,659	5,659,984	4.70

Table 2
NRREP's subsidy and credit requirements for RETs [6].

2012–2016	Average annual targets	Subsidy (USD M)	Credit (USD M)
Hydro	Pico: 167 units—3 kW Micro: 333 units—30 kW Mini 20 units—500 kW	153.13	237.50
Solar	SHS: 60,000 units SSHS: 50,000 units	28.89	23.63
Biogas	22,000 units	113.29	103.58
IWM	LS: 320 units SS: 1750 units	1.93	1.45
ICS	Mud: 115,000 Metallic: 2600 Institutional: 220	2.83	1.07
	TOTAL	**300.07**	**367.22**

SSHS = Small Solar Home System, IWM = Improved Water Mills, LS = Long Shaft, SH = Short Shaft, and ICS = Improved Cook Stove.

Table 3
Road density per 100 km^2 in Nepal [7,8].

Ecological belt	Development regions				
	East	Center	West	Mid-west	Far west
Mountain	4.41	22.05	2.12	1.84	2.01
Hill	24.91	81.55	74.71	23.47	8.00
Terai	32.75	46.38	20.16	26.56	13.62

3 November 1996 to accelerate the implementation of the off-grid rural electrification. Since its inception, AEPC has been empowered to popularize and promote uses of renewable energy technologies (RETs), raise living standards of rural people, protect the environment, and develop commercially viable renewable energy industries. With a board of 11 members from government agencies, industry sectors and non-governmental organizations, AEPC's main responsibilities and activities include (a) formulating renewable energy polices and development plans, and (b) coordinating and facilitating the implementation of these policies and plans.

The off-grid approach for rural electrification in Nepal has been concentrating on (a) micro-hydro power development and (b) solar home systems (SHS). The Nepal Micro-Hydropower Development Association, an umbrella organization of about 50 private firms currently providing micro-hydropower services, estimates that, since the industry's earliest beginning in 1960s, around 2200 off-grid micro-hydropower plants have been constructed, which currently supply electricity to about 200,000 households [9]. The Rural Energy Development Program, implemented by AEPC and supported by UNDP and the World Bank, has alone installed more than 300 micro-hydropower units ranging from 10 kW to 100 kW, with an average plant size of about 30 kW.

AEPC has disseminated nearly 300,000 isolated solar home systems after Energy Sector Assistance Programme (ESAP) was set up by the Danish International Development Agency (DANIDA) in 1999. Table 4 presents cumulative number of solar PV systems disseminated by July 2012.

Table 4
Total number of solar PV system installed till July, 2012 [10].

System	Number	Installed capacity (Wp)
Solar Home System (SHS)	299,914	7,490,014
Small Solar Home System (SSHS)	22,605	113,025
Institutional and Pumping System (ISPS & PVPS)	138	129,210

SSHS = more than 5 Wp and less than 10 Wp, SHS = 10 Wp and above.

According to the AEPC practice, a beneficiary qualifies for SHS or ISPS if there is (a) no access of electricity in the village, and (b) no possibility of extending the national grid in next 5 years. The rate of dissemination of SHS is shown in Fig. 2. Dissemination of SHS was record high in 2010 with 80,219 units in a single year as a result of one another program of AEPC, the Renewable Energy Project (REP), a joint effort of the European Union and the Government of Nepal. Nearly 70% of the total systems installed so far were disseminated in those 4 years from 2007 through 2010. Fig. 2 presents year wise dissemination and average size of SHS in Wp from 2000 through 2012. In the recent years, however, the dissemination rate has declined, which might gain momentum after introduction of NRREP in July 2012, as well as with the rapidly falling cost of PV modules in the international market.

The solar PV technology is still not within the reach of the economic poor [12]. Both the demand and supply-side constraints exist in Nepal in parallel. Access to credit and cumbersome subsidy delivery mechanisms has been perceived as the major factors affecting the expansion of PV based off-grid rural electrification in Nepal. This technology also suffers disadvantages such as low efficiency/capacity factor, excess battery costs, etc. [13]. Innovative group insurance of risky components such as battery with premium based on management of its life cycle can help mitigate the consequences of lack of reliability. Some interrelated challenges of isolated SHS include: (a) credit facilities and interlinking with other rural development activities, (b) decentralized repair and maintenance for sustainable dissemination, (c) management of lead acid battery to reduce environmental and health hazards, and (d) quality assurance and after sales service. In recent days, it is challenging for rural people to identify and select robust products because of higher cost involved and awareness about varieties of imported products available in the market.

However, it is challenging to keep smooth operations and appropriate maintenance for community-owned off-grid electricity generation and distribution systems in Nepal, due mainly to severe shortage of technical expertise, management experience, concerted incentives and designated funds for operation and maintenance (O&M). According to a survey on a few Village Development Committees (VDCs) in the Dhading district, only 5 out of 27 established micro-hydropower units remained in operation in July 2012. Because of the heavy financial costs and high technical requirements, some villages have indicated that they might prefer to wait for grid connection, despite the long wait and the unreliable electricity supply that is constrained by chronic load-shedding arrangements. In some cases [14], gaining access to the national power grid has been taken as an indicator of

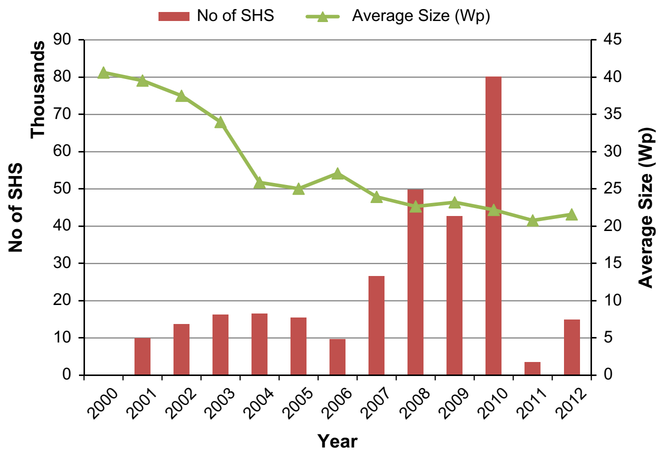

Fig. 2. Yearly installations of SHS and average size [11].

development and hence has been pushed forward without exploring alternative options such as off-grid systems.

The off-grid approach mainly focuses on remote rural areas generally characterized by low population density, low load factor, and geographical remoteness [15,16]. In addition, the targeted consumers of the rural electrification programs in Nepal have lower disposable incomes and often find difficulties to pay even the minimal electricity tariff that compete with basic sustenance. Due to such unsustainable environment (economically vulnerable and marginal market), private investors are reluctant to invest in the rural electrification sector [17].

2.2. The on-grid approach

Rural electrification through power grid extension has been carried out mainly by the Nepal Electricity Authority (NEA), which was created by GON on 16 August 1985 as the sole state-owned utility to monopolize over electricity generation, transmission and distribution in the country. NEA has adopted six different modalities for rural electrification [18], which can be financed through various channels (such as specialized project or grant programs, and annual government budgets, or NEA's own budgets). In February 2003, NEA enacted "Community Electricity Distribution Regulation-2060" [19] to promote and regulate activities for rural electrification via extending the national power grid. According to this regulation, 80% of the project costs will be provided by the government, whereas the remaining 20% have to be covered by the hosting communities. The hosting community should form a legal entity, the Community Rural Electrification Entity (CREE), to buy electricity in bulk from the NEA at a reduced price (3.5 NRs per kWh plus 0.10 NRs for line rent) and to sell electricity to its consumers on a household meter base. The basic tariff for households is NRs 4.0 per kWh for the first 20 kWh a calendar month. The 20:80 schemes are perhaps the country's biggest development program that are still very popular with the rural communities. With the appropriate financial and institutional support, socially orientated co-operative businesses can be a willing, efficient and effective means of extending and managing rural electricity services [20].

In 1999, the Asian Development Bank (ADB) supported a rural electrification project, to expand NEA's rural grid in the eastern, central, and western regions [21]. This consisted of (i) newly supplying rural areas in 22 districts with 13 rural electrification schemes in the plains and 9 in hill districts and (ii) constructing new 33 kV lines and substations. The rural electrification component served 240 village development committees; connected 154,000 rural households, or 860,000 residents of poor rural areas; and constructed 9 new 33/11 kV area substations, 694 11 kV/low voltage distribution transformers, 1150 km of 11 kV lines, 117 km of 33 kV lines, and 1314 km of low-voltage lines. It was estimated that this project had increased the number of NEA customers by 22% and improved the rural electrification rate from 14.6% to about 18.0%.

After second revision, the ADB loan account was closed in 2008. NEA completed the remaining works using its own resources. By the end of FY2011, when all the remaining works were completed, an estimated 119,000 new consumers had been connected to the grid. Of 22 substations constructed or upgraded under the project, 4 have been further upgraded in response to high demand and 12 are running at full capacity. The remaining 6 substations are currently running at 70% of their installed capacity [21].

Meanwhile, some independent power producers, such as the Butwal Power Company, the Salleri Chaialsa Electricity Company, and the Khumbu Bijuli Company, have carried out certain grid extension activities in some relatively isolated rural areas where they generate and distribute electricity, as part of their corporate social responsibilities. The South Lalitpur Rural Electric Co-operative Ltd. (SLREC) is one of the most cited examples of success by the National Association of Community Electricity Users of Nepal and its promulgator. Established as a non-profit organization by the United Mission of Nepal (UMN), the Butwal Power Company Ltd. (BPC) is another non-NEA agency that has implemented grid-connected rural electrification. Nowadays almost all independent power producers are required to serve the rural communities they are in as a part of their power purchase agreements with the NEA.

With funding from USAID in 2006, a Rural Electrification Global Development Alliance of Nepal (REGDAN), a partnership of local power companies (e.g., BPC and SLREC) and Winrock International Nepal, was formed to facilitate sustainable and cost-effective expansion of electrification services to rural regions not previously served. Winrock International Nepal supported a study on possible ways to minimize the rural electrification cost in the Nepalese context [22]. Most REGDAN activities have focused on capacity building at the local community level.

With NEA, Ministry of Energy and AEPC as an implementation partner, the World Bank supported Nepal Power Development Project (NPDP) since March 25, 2004. Even after revision of original closing date of June 30, 2009 to December 31, 2012 the implementation status report [23] rates the project "Moderately Unsatisfactory" in terms of both implementation progress and progress toward achievement of project development objectives. The objectives of the Nepal Power Development Project are to: (a) develop Nepal's hydropower potential in an environmentally and socially sustainable manner so as to help meet electricity demand; (b) improve access of rural areas to electricity services; and (c) promote private participation in the power sector as a way to improve sector efficiency and to mobilize financing for the sector's investment requirements. The project consists of three components, namely: (a) establishment of a Power Development Fund (PDF) to finance private development of small- and medium-sized hydro-schemes; (b) community-based village electrification through construction of micro-hydro systems (sizes of up to 100 kW); and (c) grid transmission and distribution improvements. Out of these three components, community-based micro-hydro village electrification component of the NPDP is the "the most successful" and "clearly the best at meeting and even surpassing targets" [24].

3. Consumer and government perspective

3.1. Consumer perspective

Remote rural consumers approach all options available to them to electrify the community they live in; as has been shown, these are offered mainly by government institutions. These communities tend to

utilize multiple levels of negotiations at different stages of the project development. For these indigent people, off-grid electrification is a temporary solution that requires both capital investment as well as O&M of the system the responsibility of the beneficiary, while urban people enjoy plug-and-play electricity that can support wider range of power for end users whose O&M is taken care by the state owned utility, it is hard to justify less the privileged rural community electrification model involving equity of the beneficiary and sense of dignity of local generation in the name of so called local ownership approach. The government rather creates a favorable business environment (through appropriate policy) to promote private entrepreneurship in rural electrification. Cross-subsidy can be utilized to finance rural electrification to bring down cost of electricity to grid parity, and to boost confidence of private entrepreneur in this business.

For those communities it does not matter which local resource they utilize for electricity as much as the reliability and consistency of the electricity supply. Unless a business model of off-grid rural electrification can deliver these services (major attributes: continuous supply and ability to serve a range of power) associated with the on-grid approach, that model continues to be a short term solution (pre-electrification option), and those communities always aspire for on-grid electricity. Hence the long term rural electrification model must have characteristics of a on-grid model and assurance from the local planning authority about their continued technical and other supports to maintain supply side reliability.

A study conducted by ESAP/AEPC to estimate the impact of mini-grid electrification suggests that minigrid is not only a major source of electricity in rural areas but also has a positive impact on various socio-economic variables, and has met households' expectation at the inception phase [25].

3.2. Government perspective

AEPC is on the process currently undertaking one of its periodic revisions of the Subsidy Policy for Renewable (Rural) Energy 2009 [26]. As presented in the stakeholder consultation meeting on Oct 4, 2012, the new revision might take into account spatial variation within the country and other local development indices as basis for subsidy. The proposed subsidy [27] across different RETs exceeds the previous level but does not specify any additional source of subsidy. A representative from Ministry of Finance cited different inefficiencies the subsidy has brought to the market, and reiterated the intention of GON to replace the subsidy gradually by credit in the long run. Although critics blame the anti-subsidy policy as being imposed at the request of the donor community, there are divided opinions among government representative and political parties regarding the gradual phasing out of subsidies.

Whatsoever, different drivers (economic, social and environmental) including the UN initiative to achieve universal access to modern energy services by 2030 have catalyzed GON to launch an ambitious but a necessary program, the NRREP, 2012. To achieve a common goal of rural electrification, the on-grid electrification planning headed by NEA (and implemented by local government) must complement with the off-grid approach by the AEPC. With these two lead agencies in the domain of two different ministries[1], the National Planning Commission may be an appropriate agency to coordinate (synchronize) the UN initiative in Nepal.

[1] In May 2012, the Cabinet had decided to hand AEPC, one of the most resourceful sections of then Ministry of Environment, over to the Ministry of Energy, while the latter was quite eager to embrace the change, the decision was withheld and the center was decided to remain under the purview of the Ministry of Environment which is now merged with Ministry of Science and Technology to form Ministry of Environment, Science and Technology.

4. Quantitative decision parameters

Comparison of the cost of national grid extension to the cost for off-grid system should be carried out in order to justify or negate the decision on investing in an off-grid electricity generation system. It is a common practice to calculate and rank the total net present costs (NPC) for different feasible engineering designs to find the least-cost approach to achieve the same economic purpose in terms of meeting the demand for electricity in the village. Meanwhile, it is also very useful to compare (a) the breakeven grid extension distance, (b) the levelized energy cost, (c) average capital cost per household, and (d) the reliability of energy supply to pinpoint to the actual degrees of differences among different approaches.

4.1. Net present costs

The total NPC represent the full cost of a system, and condense all the costs and revenues that occur within the project lifetime into a single lump sum in present dollars, with future cash flows discounted back to present using the discount rate. Costs may include capital costs, replacement costs, O&M costs, fuel costs, costs of buying electricity from the grid, insurance costs, and miscellaneous costs such as penalties resulting from pollutant emissions. Revenues may include income from selling power to the grid, plus any salvage value at the end of the project lifetime. When calculating the NPC, costs are positive and revenues are negative, which are just opposite to the process for calculating the net present value.

The net present cost of establishing and operating a stand-alone renewable energy system, NPC^{RE}, can be represented as:

$$NPC^{RE}(E) = \sum_{n=1}^{N} (k_n^{RE} - s_n^{RE}) W_n(E) + \sum_{t=1}^{T} \frac{o_t^{RE}}{(1+i)^t} + MG(E) \tag{1}$$

where E is the designed total annual electricity supply target in kWh, based on the assessment of electricity demand in the village,N is the total number of renewable energy technologies adopted, T is the project lifespan in year, when the salvage value will be near zero[2], i is the discount rate in % (normally taken as the interest rate), $W_n(E)$ is the installed capacity for nth type of RET, in kW, optimized in a portfolio way to meet the load demand in the village, in kW, k_n^{RE} is the unit capital cost for the nth type of RET, in US$ per kW, s_n^{RE} is the subsidies from all sources for the nth type of RET, in US$ per kW, o_t^{RE} is the O&M costs in year t, in US$, which includes the cost for replacing energy storage systems (e.g., the battery bank) and $MG(E)$ is the NPC associated with marginal cost of energy to meet demand forecast.

The net present cost of extending and operating a transmission line over a distance of D kilometers, NPC^{GE}, can be represented as:

$$NPC^{GE}(D) = (g^{GE} - s^{GE})D + \sum_{t=1}^{n} \frac{o_t^{GE} D + p_t(1+\delta)E_t}{(1+i)^t} + MG(E) \tag{2}$$

where g^{GE} is the unit capital cost of grid extension in US$ per km, s^{GE} is the subsidies for grid extension in US$ per km, p_t is the price to purchase electricity from the grid in US$ per kWh, o_t^{GE} is the O&M cost of grid extension in US$ per year per km, and δ is the line-loss factor in percentage.

The decision rule can be simply expressed as that a stand-alone renewable energy system should be established if

$$\frac{NPC^{RE}}{NPC^{GE}} < 1 \tag{3}$$

[2] Any salvage value can be utilized to reduce any footprint of the project on the environment.

which can be rewritten as, assuming $MG(E)$ comparable for the both the schemes:

$$\left[\sum_{n=1}^{N}(k_n^{RE}-s_n^{RE})W_n(E)-(g^{GE}-s^{GE})D\right]+\sum_{t=1}^{T}\frac{o_t^{RE}-[o_t^{GE}D+p_t(1+\delta)E_t]}{(1+i)^t}<0 \quad (4)$$

The first part is the difference on upfront capital cost, and the second part is the gap in operational costs. A mistake can happen if only the first part is taken into consideration while the operational costs over the project's lifespan are ignored.

4.2. Breakeven grid extension distance

According to an energy modeling software for hybrid renewable energy systems, HOMER [28], the breakeven grid extension distance (BEGED) is defined as the distance from the grid at which NPC^{GE} equals NPC^{RE}. Substitution would lead to the following formula to determine the BGED, $D^{(*)}$:

$$D^{(*)}=\frac{\sum_{n=1}^{N}(k_n^{RE}-s_n^{RE})W_n(E)+\sum_{t=1}^{T}\frac{o_t^{RE}-p_t(1+\delta)E_t}{(1+i)^t}}{g^{GE}-s^{GE}+\sum_{t=1}^{T}\frac{o_t^{GE}}{(1+i)^t}} \quad (5)$$

4.3. Levelized energy cost

The levelized energy cost (LEC) is defined as the price at which electricity services generated from a specific source must be paid to break even over the lifetime of the project. It is very useful to calculate such costs for different approaches to meet the same electricity demand and find out which approach is most efficient. The LEC for a stand-alone renewable energy system can be calculated as:

$$LEC^{RE}=\frac{\sum_{n=1}^{N}(k_n^{RE}-s_n^{RE})W_n(E)+\sum_{t=1}^{T}\frac{o_t^{RE}}{(1+i)^t}}{\sum_{t=1}^{T}\frac{E_t}{(1+i)^t}} \quad (6)$$

The LEC for grid extension can be calculated as:

$$LEC^{GE}=\frac{(g^{GE}-s^{GE})D+\Sigma_{t=1}^{n}\frac{o_t^{GE}D+p_t(1+\delta)E_t}{(1+i)^t}}{\Sigma_{t=1}^{T}\frac{E_t}{(1+i)^t}} \quad (7)$$

For a level playing field, the subsidy on renewable off-grid schemes should be such that LEC would equate to the grid parity that is the point at which means of generating electricity from renewable energy produce power at a level cost that is equal to or less than the price of purchasing power from the grid.

4.4. Average capital costs per household

The BEGED analysis of a project sometimes may not take account of merits the grid might bring to other household or village neighboring the project village. In Nepal the average capital cost (per household, HH) for grid connection ranges roughly from US$100 to US$300 depending on the spatial distribution of HHs, type of settlements and the client delivering the on-grid project [29]. An ESMAP supported study [30] further confirms the capital cost range. Costs are cut when communities lead electrification efforts. The cost of per household connection may be up to three times lower when communities get involved. One reason for lower cost is that NEA pays for the higher capacity hardware, while the low capacity transmission lines and substations fall on the user groups' plate [31].

The average cost of electrification per household in Nepal is US $264 using micro-hydro, and US$432 using PV [32]. Meanwhile, the average cost of extending the gridline itself (i.e. excluding the cost of generation) is US$300 per household (estimating that averages of 16 households are served by each km of extended gridline) [33]. Reference [34] has estimated that an off-grid technology is a better option than grid extension for electrification in developing countries if there are less than 100 clients per kilometer of national gridline extension. For a typical demand of 65 kWh per household per year [35], it is found that the cost of delivering electricity by centralized generation and grid distribution is up to four times the cost of stand-alone and mini-grid options. For the government of Nepal, off-grid technologies have been an attractive option for promoting electrification whereby government investments are used to complement investments by the beneficiary and other sources. Off-grid electrification using RE is a more viable and attractive option compared to the extension of grid lines, particularly in rural areas with scattered populations, difficult geographical terrain and low energy demand.

4.5. Reliability of energy supply

Currently Nepal is in acute shortage of electricity. NEA's “load shedding” schedule (or its derivatives such as smart phones application *BattiGayo*) has been a must have document in every home and business. A new timetable published by NEA on Feb 3, 2013 shredded load-shedding hours from previous 97 h per week to 84 h per week. With NEA's forecast that load-shedding during the winter could go up to 21 h a day, the Prime minister decided to intervene including bilateral talk with Indian counterpart to supply 200 MW to Nepal. The Ministry of Energy (MoE) has asked the government for NRs 1.25 billion to implement its Load-Shedding Reduction Action Plan that aims to bring down power cuts to 12 h daily during the dry season. These load-shedding hours do not seem to decrease significantly until the Upper Tamakoshi (456 MW) plant which is scheduled to be completed by April 2016, will reinforce Integrated Nepal Power System (INPS).

Due to frequent unscheduled power cuts even in the capital city of Kathmandu, many villagers suspect that electricity may not be supplied even after the grid lines are extended to the village. Tapping into local renewable energy will give the villagers better confidence on supply side reliability. Nepal is in dire need of reliable power supply to maintain economic and development activities.

5. Pilot project: ADB technical assistance

In order to test and demonstrate the technical feasibility and financial viability and to establish a scalable implementation model for developing local renewable energy in poor remote villages, Asian Development Bank (ADB) has launched a Regional Technical Assistance (RETA-7485, Effective Deployment of Distributed Small Wind Power Systems in Asian Rural Areas [36]), as an important part of ADB's “Energy for All” initiative, targeting the alleviation of energy poverty, protecting the local environment, and achieving inclusive and sustainable growth in rural areas that are without reliable and affordable access to modern energy at present. Nepal has been selected as the first pilot country for the RETA, and the AEPC of the Ministry of Environment, Science and Technology has been functioning as the Implementation Agency (IA) for the pilot projects in Nepal. The pilot project resides in the Hill regions of western Nepal.

After careful data comparison and field visits on about 10 candidate sites, Dhaubadi VDC Ward No. 1, Nawalparasi District, in the Lumbini Zone of western Nepal, was chosen to host the first pilot project. This village is located at latitude 27°46′N and longitude 84°07′E (WGS 1984) with an altitude of 1203 m. It is 23 km north of the East–West highway from Daldale, Nawalparasi, and 17 km away from the nearest national power grid connection point, Munde, which is 6 km north of Daldale, where the electricity supply became available only recently in 2011. The nearest major town, Narayangadh, is 50 km away, and the capital city, Kathmandu, is 160 km to the east. The village is truly isolated but still is accessible by a seasonal road. It takes 3 h by vehicle with a travel fare of NRs 165 (nearly US$2.00) to go to the nearest market center, Daldale, to buy items such as batteries, candles, and kerosene or to visit a doctor.

Currently, 333 people in 46 households are living in Dhaubadi VDC, with an average family size of 7.24.

Based on the assessment on indigenous renewable resource availability and the assessment on local energy demand for the short-, medium- and long-term periods, an integrated approach was adopted for the pilot project. Renewable energy technologies with strong complementarities have been utilized to maximize system efficiency and reliability, to reduce overall costs and complexity, and to enhance financial viability and economic values. Following best practices of the hybrid system design [37], the system consists of (a) two wind turbines, each with a rated capacity of 5 kW and (b) 18 solar photovoltaic (PV) panels of 120 Wp each (2.16 kWp total), with a mini-grid distribution network, to (a) displace kerosene, batteries and candles for lighting at home, schools, police station, and other public places, (b) save the time needed to go to the market to buy kerosene and batteries, (c) enable operations of an agro-processing center and a health post, and (d) improve safety in the village through providing street lights. The technical configuration of the hybrid design bases on forecasted demand for the mid-term year which is year 2018.

5.1. Quantitative analysis for the ADB pilot project

The following analysis focuses on the electricity generation system. The relevant data and calculation results are presented in Table 5. The total net present cost of the stand-alone power system is composed of three parts: (a) the net cost that must be financed for the pilot project in the base year (US$79,538—about 50%), after taking all deductibles, subsides, credits and grants into consideration, (b) the costs of replacing the battery bank twice (US$36,140—about 23%) in the project lifespan of 20 years, and (c) the net present value of O&M costs for 20 years (US$42,738–about 27%). The estimated costs for grid extension and for electricity supply from the grid (at NRs 4.0 per kWh for the initial 20 kWh—a heavily subsidized tariff) have been obtained from the Nepal Electrical Authority. In order to calculate the capital recovery factor, the interest rates of the Clean Energy Development Bank of Nepal [38] are taken, standing at about 16%, which reflect serious concerns by commercial lenders in Nepal on continuous inflation and inherent risks related to wind and solar energy projects, especially in remote villages with weak management capacities.

Therefore, the BEGED for the pilot project is 10.2 km, which is only about 60% of the actual distance to the nearest grid connection point. This result is not surprising, mainly because:

- Extending the 11 kVA transmission lines in mountainous areas of Nepal are very costly, mainly because of (a) geological reasons, (b) technical reasons, and (c) management efficiency reasons. The capital cost to connect the pilot village over a full distance of 17 km amounts to US$200,555, which can be used to build more than two stand-alone power generation systems. In other words, the initial capital cost of the stand-alone power system can be used to extend the power grid by only 6.7 km, which is only about 40% of the physical distance of the project site from the nearest grid.
- The annual O&M cost for grid extension is also very high, may be due to line loss, natural disaster etc., amounting to US $7078.4 per year for the 17-km transmission lines—more than double the O&M costs for the stand-alone power generation systems.
- The real interest rate is heavy, at 11.54% per year, leading to a high capital recovery factor of 13.0% because of high inflation rate. Average inflation rate during the fiscal year 2011/12 was 8.0 percent [39]. With such a high inflation, earning or saving of rural people will be consumed for basic sustenance and less money will be available for tariff or equity share to support access to energy forcing rural people to vicious circle of poverty.

As illustrated in following Fig. 3 that compares the costs of two possibilities for supplying electricity to the pilot project site, the annualized cost of the stand-alone off-grid system is independent of the grid extension distance (as a flat line), whereas the annualized cost of extending the grid depends on the grid extension distance. The intercept of the grid extension cost corresponds to the cost of supplying power from the grid to meet the demand for electricity in

Table 5
Computation of the breakeven grid extension distance.

Cost estimates		**US$**	**NRs**
Total net present cost of the stand-alone power system	C_{NPC}	158,416	11,413,841
Initial system cost		79,538	5,730,682
Battery replacement cost		36,140	2,603,887
O&M costs		42,738	3,079,272
Cost of power from the grid in US$ per kWh	c_{power}	0.0555	4.0
Capital cost of grid extension in US$ per km	c_{cap}		
Cost of 11 kVA transmission line		11,797	850,000
Cost of 400/230 V distribution line		7634	550,000
O&M cost of grid extension in US$ per year per km	c_{om}	416	30,000
Total cost for full extension		200,555	14,450,000
Parameters of breakeven grid extension distance analysis	**Symbol**	**Value**	
The physical distance from the pilot project to the grid in km	d	17	
Subsidy for grid extension (%)	s	80.00	
Capital recovery factor (%)	CRF	13.0	
Interest rate in %	i	16.0	
Real interest rate in %		11.54	
Project lifetime in year	R_{proj}	20	
Total annual electrical demand (primary plus deferrable) in kWh	E_{demand}	12,272	
The breakeven grid extension distance in km	D^*	10.2	
The breakeven distance as % of the physical distance		60.0	
Ratio between the initial system cost and			
Capital cost of grid extension in km		6.7	
Total cost for full extension (%)		39.7	

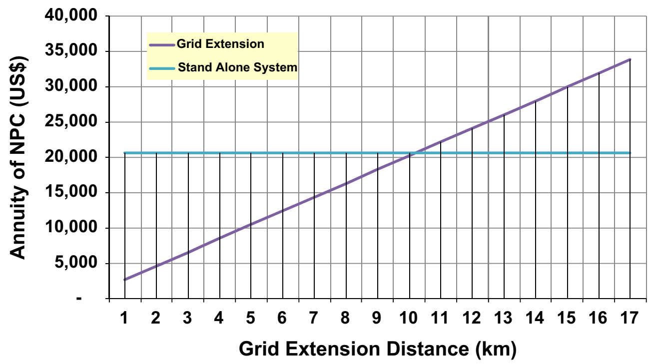

Fig. 3. Breakeven grid extension distance.

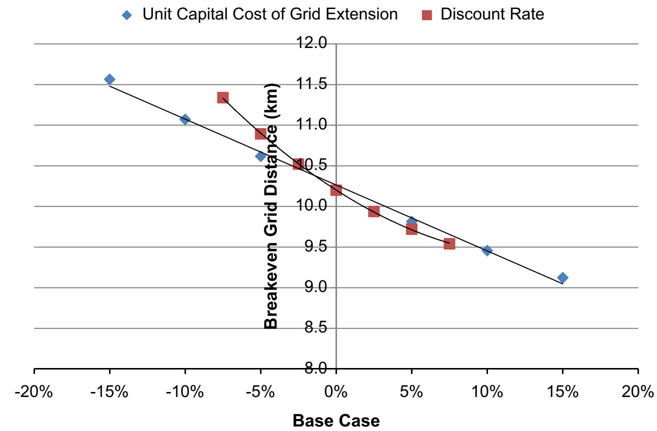

Fig. 4. Sensitivity analysis of breakeven grid extension distance.

the village. The slope corresponds to the net present cost of grid extension in US$ per kilometer. The distance at which the costs equate is the BEGED, which is 10.2 km for the hosting village of the pilot project. This further justifies appropriateness for establishing a stand-alone system rather than connecting the pilot village with the national grid. However, while extending grid to the hosting village the same grid might serve other villages en-route to the project village or in the neighborhood of grid extension path.

5.2. Sensitivity analysis

A study of the World Bank (in year 2000) [40] on rural electrification programs estimates the average cost of grid extension per km at between $8000 and $10,000, rising to around $22,000 in difficult terrains. In India, these costs tend to be at the lower side due to use of small conductors and local manufacture of the major components. These cost positively correlate with recent appreciation of cost of raw materials (constituents metals). Hence the base case value of $11,797 represents an average price for difficult geographic terrains and scattered settlement of Nepal. Alliance for Rural Electrification publication [41] summarizes small wind costs and financing trends.

Eq. (5) shows that the BEGED is a function of: (a) capital and O&M cost for grid extension, (b) capital and O&M cost for off-grid system, (c) financing costs and discount rate, (d) per capita energy consumption in the village and reliability of electricity supply, and (e) environmental and economic costs and benefits the project brings in to the hosting village. Variables related to national grid extension are mainly grid capital cost ($/km), grid O&M cost ($/year/km) and grid power price ($/kWh). Fig. 4 presents sensitivity of BEGED in the range between $\pm$15% of capital cost of grid extension and $\pm$7.5% of the discount rate of base case scenario. Due to low per capita energy consumption in rural areas, the BEGED is a weak function of grid power price ($/kWh) even at double of the mean grid power price in rural Nepal.

Since both electrification schemes are capital intensive, the interest rate is another important factor for deciding the mode of rural electrification. For every percent decrease in the discount rate, the BEGED increases by almost 1.5%. Similarly, the grid capital cost ($/km) negatively correlates with BEGED. The BEGED is robust to alternate assumptions regarding capital cost of grid extension and the discount rate.

At the current subsidy level (80%) on capital cost of on-grid rural electrification, and theoretical subsidy of 28.4% on stand-alone wind solar hybrid system, the subsidy of national grid extension should be raised by 2.38% to equalize the NPC of both systems to $116,510. This further justifies the use of stand-alone systems compared to national grid extension. Even though the subsidy for stand-alone system in Nepal is low compared to national grid extension subsidy, the stand-alone system stands out in the context of the pilot project. Many other projects have demonstrated that decentralized renewables are a more reliable electricity resource than grid connectivity due to the over-stretched and unreliable capacity of central systems [42].

Apparently, a stand-alone system is preferable, if (a) the village is located farther away from the grid, (b) the stand-alone system can operate for a longer lifespan, (c) the financing cost (i.e., the interest rate) for capital expenses of the system can be lower, (d) the total electricity demand in the village is higher, (e) the capital and O&M costs of grid extension are heavier, and/or, (f) the cost of power from the grid is more expensive.

6. Implication for rural electrification in Nepal

This pilot project is a second wind after infamous NEA failure of two 10 kW turbines in Mustang in 1989 [43]. Sustainability of the pilot project is the key to retain momentum of small wind energy industry and secure future funding for rural electrification scheme that utilizes the small wind energy technology. After this pilot project the awareness levels in adopting wind energy technology and willing ness of people to access and pay for electricity have increased significantly in the pilot village. However there is still a huge financial gap between cost of electrification and the affordability of rural people [32].

AEPC initiated a Solar and Wind Energy Resource Assessment (SWERA) Project in 2003, in partnership with the Center for Energy Studies, Institute of Engineering and with the support from United Nations Environment Program/Global Environment Facility (UNEP/GEF). Derived from the SWERA map [44], Fig. 5 presents a map of probable villages at distance outside 4 km buffer from transmission line in Nepal with wind power density greater and/or equal to 40 W/m^2 and solar insolation greater than 3.9 kWh/m^2/day, and number of household greater than 15 within minimum bounding square of side 2 km.

Considering BEGED of 4 km, more than 2600 villages covering about 18% area of Nepal can be electrified utilizing only the wind/solar hybrid system. The number of village reduces to 500 if the BEGED is 10 km. Table 6 presents the number of probable village for off-grid electrification for buffer distance of 4 km and 10 km with wind power density 40 W/m^2 and solar insolation of 3.9 kWh/m^2/day. This analysis does not take into account the possibility of electrifying the village with micro-hydro which receive priority over the wind solar hybrid system in Nepalese context [26].

Subsidy to the on-grid rural electrification has unknowingly overtaken the niche market for the stand-alone off-grid system in Nepal. Data from the pilot project suggest that the subsidy on capital

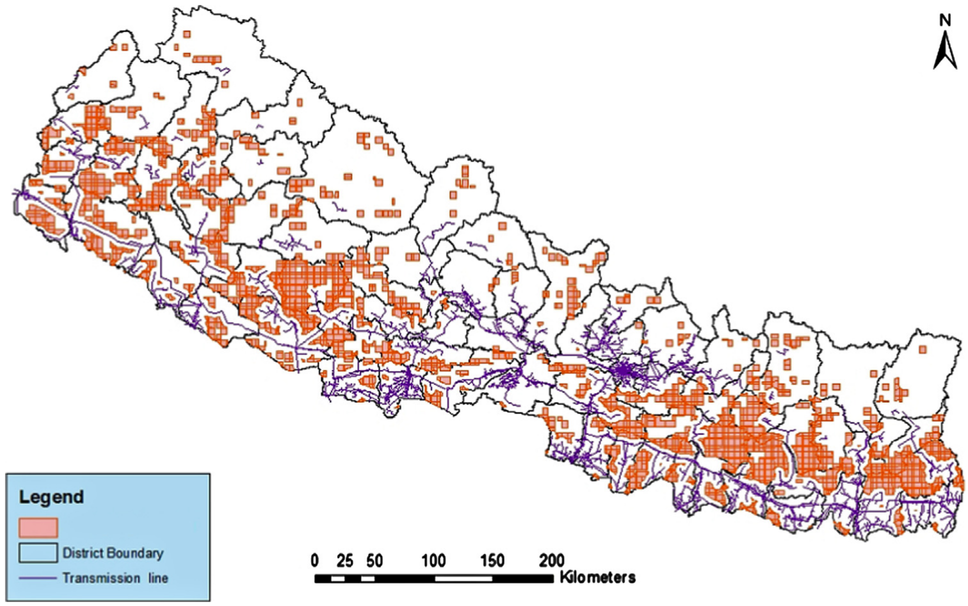

Fig. 5. Probable villages for stand-alone off-grid system (wind/solar hybrid) in Nepal.

Table 6
Villages suitable for wind/solar hybrid system (with HH #>15).

S. no.	Wind potential Ć (W/m^2)	Solar PV potential (kWh/m^2/day)	Grid distance (km)	Village no.	Area (km^2)	Area (%)
1	≥40	>3.9	4.0	2629	27,196	18.48
2	>40	>3.9	4.0	2121	22,729	15.44
3	>40	>3.9	10.2	522	6794	4.62

cost grid extension should be reduced to 51.5% to establish a level playing field for the off-grid system. At this subsidy level, the net present cost of both systems will be equal to $177,530.

Many remote rural settlements especially those in remote mountainous villages (of Nepal) can be electrified cost effectively by off-grid with their own renewable resources with appropriate policy in place and introduction of private sector/entrepreneur in the form of Rural Renewable Service Company (RuRESCo) or its derivatives under the Engineering, Procurement, Construction and Maintenance (EPC-M) model for an annual premium. It is absolutely necessary to ensure reliability of the off-grid system to further the acceptability of stand-alone system. In the same way the NEA takes care of O&M of on-grid option, those less privileged rural communities could be supplied with electrification through public–private partnership by enacting appropriate policy. If this does not happen, off-grid rural electrification would be a temporary solution that will waste government (or donor support) resource that could otherwise be spent in other infrastructure development projects.

Off-grid electrification must complement grid expansion. The government could prepare a master plan to keep certain areas off-grid (based on quantifiable parameters such as the BEGED or average capital cost (per household) with national power grid or their combinations) in a form of *zoning*. Zoning is a device of land use planning used by local governments. The nature of the zoning regime may be determined or limited by state or national planning authorities or through enabling legislation. The primary purpose of zoning is to segregate areas that are thought to be viable for the stand-alone off-grid system from the threat of haphazard extension of grid. In practice, zoning is used to prevent new development from interfering with existing businesses and to not duplicate government resource for redundant development activities.

Renewable energy based off-grid electrification may bring in grant money from donor agencies which may not be available to the GON even as a loan should it elect to electrify rural village extending the national grid. We should not stare at renewable resource of energy blindly, neither promote off-grid system only for the sake of the environment nor blow on-grid system out of proportion leading hours of power cut a day.

Encouraging private sector into the business is necessary to increase investment and allow for a wider adoption of renewable technologies in less developed economies like Nepal [45]. Private sector in the form of RuRESCo as in the case of the pilot project or its derivatives can provide reliable off-grid electricity to the community in those zones. A smart subsidy in parallel with zoning not only creates a favorable business environment to the private sector but also helps to mobilize the sector in economic development and for poverty alleviation in rural areas. With such a policy in place, sooner or later, interest of private sector is bound to grow for rural electrification perhaps faster than we can think of.

7. Summary

This article reviews ongoing rural electrification efforts in Nepal and compares relative merits of each approach from perspective of the beneficiaries and the government organization implementing those electrification schemes, mainly the state-owned utility, the Nepal Electricity Authority, and Alternative Energy Promotion Center. Although, some qualitative measures are in practice to segregate areas for off-grid (stand-alone, mini-grid) from on-grid electrification, those measures do not seem enough to best utilize available resource to the shared objective of both schemes, as the later scheme seems intruding the domain of former scheme in the form of haphazard grid expansion. Some merits of on-grid electrification (range of power available, and O&M by the utility) that have been missing in the off-grid model, have made its beneficiary consider it as a temporary/complementary solution and always aspire for an on-grid solution. We propose some quantitative decision parameters such as net present cost, breakeven grid distance, levelized energy cost, average capital cost per household and reliability of energy supply etc., for zoning, and propose a business model to deliver equivalent service through off-grid approach mobilizing private

entrepreneur to complement governments efforts and resource with reference to a pilot project implemented in western Nepal.

The ADB supported wind solar hybrid project in Nawalparasi has demonstrated in Nepal that the wind solar hybrid system can be technically feasible and economically viable to meet basic needs for modern energy in remote poor villages not yet served by the national power grid. Moreover the project has resuscitated a hope among wind energy and renewable energy communities, and the utility, NEA scared of complete failure of the Kagbeni wind energy project two decades ago in Mustang. It has tested a scalable implementation model in the form of Rural Renewable Service Company that utilizes local know-how to harness locally available renewable energy (mainly, wind, solar) for rural electrification. In March 2012, GON forwarded ADB its interest to replicate the project in 400 remote villages of Nepal and requested support from the Asian Development Fund.

A significant number of villages in rural area covering more than 18% of Nepal can be electrified utilizing the off-grid stand-alone system using only the wind/solar hybrid system. Zoning could be a planning tool that could motivate private entrepreneurs for rural electrification and catalyze complementary investment of private sector with higher confidence on investment. Even though some other risks do exist, the business model involving the private sector, as demonstrated in the pilot project, can bring in some of those attributes (power range and reliability) of on-grid electrification to off-grid system that beneficiary normally strive for a socially acceptable model.

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